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FINAL REPORT

PROJECT B-251

PARTICULATE SIZE ANALYZER USING ION-COUNTER PRINCIPLE

By

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This report contains 40 pages.

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I. SUMMARY

A portion of airborne particulate matter always carries an electric charge equivalent to one electron for the smallest sizes and from several to many electronic charges for larger ones. Such charged particulates are known as air ions; they are charged as a result of natural ionizing radiation, thermionic emission, etc. This investigation sought to develop an electronic instrument that would permit determining the size distribution of particulates from measurements of the charges carried by the particulates and, if possible, to charge particulates in proportion to their size so that a wide range of sizes might be covered.

No way was found to accomplish size-dependent charging without at the same time precipitating most of the particulates. Instruments, however, were constructed with which particulates between about 0.01 and 0.1 micron in radius -- the size that at equilibrium rarely carries more than one electron charge -- could be analyzed. The instruments behaved quite satisfactorily on synthetic aerosols with particle sizes concentrated in this range. On natural aerosols their utility is limited apparently because there exist in this size range only a few particulates that are charged.

II. INTRODUCTION

The aim of this investigation was to develop the ion-counting technique, i.e., the method of analyzing airborne particulates by measuring their rate of migration in an electric field, into a more generally useful tool for air pollution evaluation. Charging particulates in proportion to their size was the goal, but, since no way was found to do this without precipitating a great portion of them, final efforts were devoted primarily to designing and building ion-counter systems capable of extracting the greatest amount of information about airborne particulates from those particulates that were naturally charged. This limited the ultimate analysis to particulates between about 0.01 and 0.1 micron in radius. These rarely have charges greater than one electron, so mobility data is directly convertible to size information in these instances.

Three distinctly different analyzer systems were constructed. The first employed two flat plates mounted opposite one another. The second was cylindrical and hence utilized an annular region as the test section. The third was by far the largest unit and made use of a stack of plates. Each design permitted more air to be analyzed for its ion content. Each required a special mathematical treatment of the data. This information, design features, and actual results are presented in the following sections.

III. THEORY OF ION CHAMBER MEASUREMENTS

The mobility, ω, of a charged particulate in air in an electric field, E, is the ratio of the terminal velocity, v, and E.

Thus

$$\omega = v/E \tag{1}$$

If the particulate carries a charge, q, the force, F, on the particulate is given by

$$F = qE \tag{2}$$

Equating this force to the viscous drag force and applying Stokes's law with a correction for slip results in

$$\omega = \frac{q}{6\pi\mu} \frac{k}{r} \tag{3}$$

where μ is the viscosity of the air, r is the particulate radius and k is the slip correction factor. From the data available [1], the slip correction for particulates comparable in size to the mean free path of air molecules at room temperature is given by

$$k = 1 + \frac{\lambda}{r} \left[A + B \exp\left(-\frac{Cr}{\lambda}\right)\right] \tag{4}$$

where λ is the mean free path of air molecules in air and $A = 1.257$, $B = 0.400$, and $C = 1.10$.

Several forms of ion chamber configuration were used. These were (1) two

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(1) Davies, C. N., "Definitive Equations for the Fluid Resistance of Spheres," Proc. Phys. Soc. 57, 259-70 (1945).

flat, parallel plates; (2) the annulus between two coaxial cylinders; and (3) a multiple, parallel-plate system. In addition, the first two chambers were used both as flow systems and as static systems while the third was used only as a static system. The interpretation of the resulting data from each system and the mode of operation have common features but the differences make it necessary to specialize at least a part of the discussion to a specific chamber and specific mode of operation.

For flow systems the primary data consist of ion current as a function of applied voltage together with the flow data. When the flow was constant, the resulting data plotted as current versus voltage showed a monctonically increasing curve with a current maximum which corresponds to the total charge carried by all of the ions entering the chamber per unit time.

For static systems the primary data are ion current as a function of time for a specific applied voltage. The area under the curve is the total charge on all of the ions in the chamber at the time the voltage was applied.

If the charge carried by the aerosol particlulate is unknown, analysis of the data can be made only in terms of mobility. If the charge on the particulate is known, mobility can be related to size through Stokes's law, suitably corrected, to obtain size information.

Numerous studies[2][3] have calculated the equilibrium charge on small particulates. Although different assumptions and different methods of calculation in these various studies have yielded somewhat varying results, the conclusion can be reached that for particulates below 0.1 micron radius a

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(2) Fuchs, N. A. "On the Stationary Charge Distribution on Aerosol Particles in a Bipolar Ionic Atmosphere" Geophisica Pura e Applicata, 56, 185-195 (1963).

(3) Whitby, K. T. and Peterson, C. M., "The Electrical Neutralization and Particle Size Measurement of Dye Aerosols" paper presented at the ACS meeting, Atlantic City, N.J., September 13, 1962.

charge greater than one electron is highly unlikely.

A. Flow Systems

The common feature of flow system ion chambers is the basic shape of the ion current versus voltage curve and the method of interpretation of such curves. The complete details of the analysis for singly charged particulates have been given by Hurd and Mullins[4] for flat cylindrical plate ion chambers and will not be repeated in detail here. The essence of the analysis will be given with reference to Figure 1 which shows a typical ion-current versus applied voltage curve. The data as shown in the figure always exhibits a monotomically increasing current versus voltage with a maximum current I_{max} which corresponds to collection of all of the ions contained in the flowing aerosol.

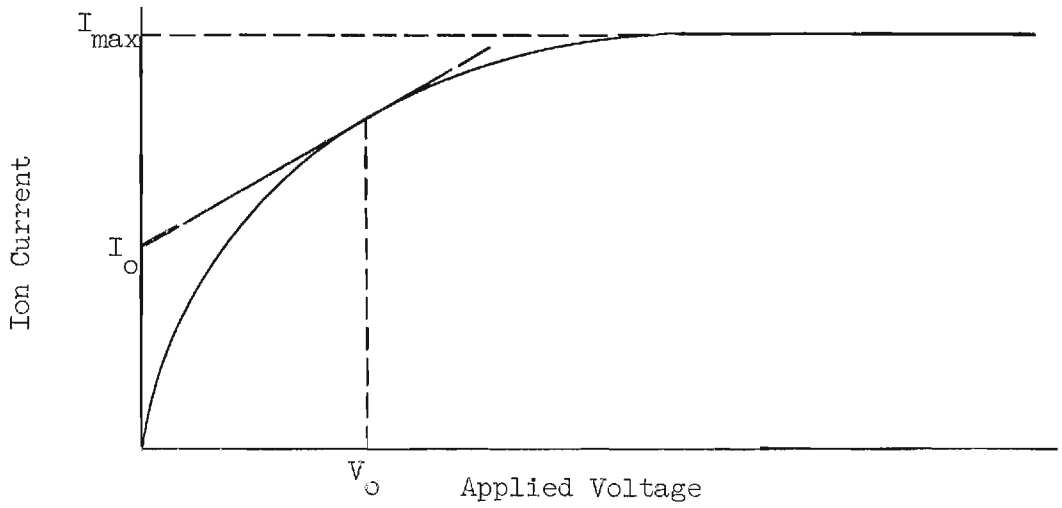

Figure 1. Typical Ion Current vs. Voltage Curve.

A line tangent to the data at V_o intersects the current axis at I_o. The

(4) Hurd, F. K. and Mullins, J. C., "Aerosol Size Distribution from Ion Mobility," J. Colloid Sci. 17, 91-100 (1962).

analysis shows that I_o/I_{max} is equal to the fraction of the total particulates in the distribution with a mobility, $\omega > \omega_o$, where ω_o is the mobility which will be totally collected at the applied voltage, V_o. The relationship between V_o, ω_o, flow rate, and particulate radius, r_o, depends only on the geometry of the system and is a constant for any given ion chamber. A similar analysis was made for the two other flow systems used in this work.

B. Static Systems

In a static system the chamber is filled with the aerosol to be examined, and at time, t=0, a voltage, V_o, is applied between the plates of the system. The current is recorded as a function of time. The resulting current versus time curves consists of an initial transient associated with the capacative charging of the ion chamber plates and with the transient response of the current meter. Following the transient response there is a monotonically decreasing "decay" curve corresponding to the migration of the ions to the collection plates. The transient response obscures the desired data at the beginning of the curve and system noise obscures the data at the end of the curve. Fortunately, neither of these effects prevent analysis of the intermediate data.

An initially uniform distribution of particulates all of charge, e, (one electronic charge) is assumed. Since the electric field is uniform, the velocity of any given particulate is constant and in particular this means that the particulates of any given mobility, ω, produce a constant contribution to the current from the time the voltage is applied until all of the particulates of that mobility are collected.

This collection time is related to the plate separation, d, by

$$d = \int_0^{t_\omega} v_\omega \, dt \qquad (5)$$

but since v_ω is constant, this gives simply

$$t_\omega = \frac{d}{v_\omega} \tag{6}$$

where $v_\omega = E\omega = \frac{V\omega}{d}$, E being the electric field intensity, and V the applied potential difference. And since Stoke's law for mobility as a function of size yields

$$\omega = \frac{ek}{6\pi\mu r} \tag{7}$$

where k is given by eq 4, the result is

$$t_\omega = \frac{6\pi\mu d^2}{Ve} \frac{r}{k} \tag{8}$$

where μ is the viscosity of air, and r is the particulate radius. Now, since all particulates with mobilities greater than ω have already been collected, the current at any particular time t_ω is due to particulates with mobilities less than ω.

It is convenient to interpret the decay curves on the basis of charge collected rather than on the basis of current. The charge collected in the interval from o to t_1 is given by

$$Q_{(o,t_1)} = \int_0^{t_1} I dt \tag{9}$$

which is just the area under the curve from o to t_1. Since the contribution to the current for those particulates with $\omega < \omega_1$ has been constant during this interval, this integral can be written

$$Q_{(o,t_1)} = \int_o^{t_1} (I-I_1)\, dt + I_1 t_1 \tag{10}$$

Similarly for any other interval from o to t_n there may be written

$$Q_{(o,t_n)} = \int_0^{t_1} (I-I_n)\, dt + I_n t_n \tag{11}$$

In these expressions the integral is the charge contributed by the particles with mobilities greater than ω_n ; the value of this integral is

$$\int_o^{t_n} (I - I_n)dt = N_n e \tag{12}$$

for particles with charge, e, where N_n is the number of particulates with mobilities greater than ω_n .

If (Q_{o,t_1}) is subtracted from (Q_{o,t_n}) there is obtained

$$Q_{(o,t_n)} - Q_{(o,t_1)} = (N_n - N_1)e + I_n t_n - I_1 t_1 \tag{13}$$

or

$$(N_n - N_1)e = Q_{(o,t_n)} - Q_{(o,t_1)} + I_1 t_1 - I_n t_n \tag{14}$$

This equation must be interpreted geometrically in terms of the appropriate area associated with the current versus time curve. A typical curve is shown in Figure 2.

In this figure it will be noted that $Q_{(o,t_n)} - Q_{(o,t_1)}$ is the area bounded by the curve from t_1 to t_n and the time axis. Adding $I_1 t_1$ to this area and subtracting $I_n t_n$ from the result leaves the area bounded on the right by the curve from t_i to t_n and bounded on the left by the current axis. Thus (N_n-N_1) is proportional to the area shown in Figure 3.

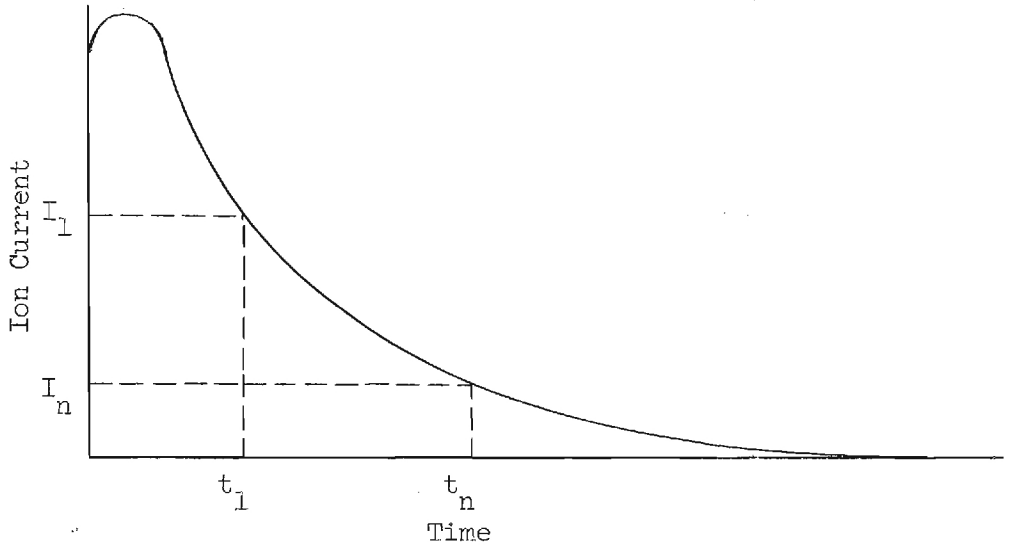

Figure 2. Typical Current vs. Time Curve for a Static System.

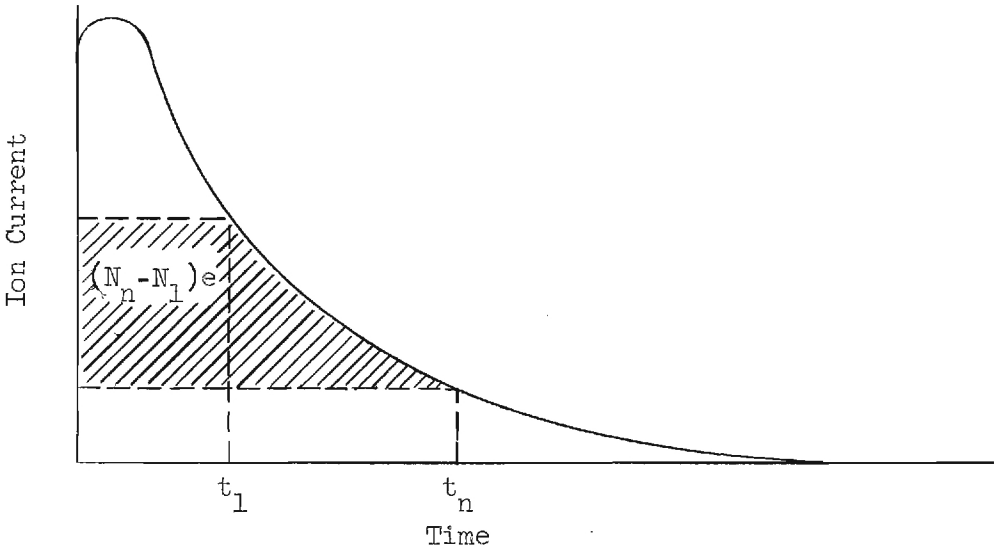

Figure 3. Typical Area Proportionality Curve

In actual curves t_1 has a practical lower useful limit due to the transient response of the system when the voltage is applied. Also t_n has a practical upper limit which is the time at which I_n is the same order of

magnitude as the electrical noise of the system. Thus the area corresponding to the number of particulates $(N_n - N_1)_{max}$ becomes the reference area and the fractional area corresponding to any portion of the distribution in the range $(N_n - N_1)_{max}$ represents the fractional proportion of the total distribution. It should be noted that mobilities corresponding to t_n and t_1 are determined by the applied voltage. Thus changing the applied voltage changes the mobility range being analysed. By using a range of voltage and normalizing the curves it is possible to construct composite decay curves to cover the entire range of interest. This was done for the data of this report.

Using the relationship between time, voltage, mobility, and effective radius, experimental data are converted in following sections to plots showing percentage less than a certain effective radius versus effective radius.

IV. EXPERIMENTAL EFFORTS

A. Particulate Chargers

1. Whitby Design

A point-to-orifice ion generator of the type used by Whitby and McFarland[5] was constructed to supply a large number of unipolar charges to an aerosol. A schematic diagram of the unit is shown in Figure 4.

The chamber was of plexiglass. The orifice and needle were of stainless steel. The spacing between the needle and orifice could be adjusted, and a number of orifice plates containing different opening sizes could be used. An adjustable potential was applied between the needle and the orifice plate with the needle connected to ground. The polarity of the potential could be reversed by exchanging the leads to the power supply. A pressure regulator was used to achieve the desired, constant, air pressure and to insure constant flow through the orifice.

2. High Velocity

A high velocity electrostatic charger patterned after the design of Langer and Radnik[6] and shown in Figure 5 was also constructed. It consisted basically of a small platinum-wire loop located in a chamber about 1 cm from a platinum-foil plate. The aerosol, surrounded by an air stream, passed between the loop and the plate, while a direct current potential was applied between the two platinum pieces.

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(5) Whitby, K. T. and McFarland, A. R., "The Decay of Unipolar Small Ions and Homogeneous Aerosols in Closed Spaces and Flow Systems," Proc. Int. Conf. on Ionization of the Air, Franklin Inst., October 16-17 (1961).

(6) Langer, G. and Radnik, J. L., "Development and Preliminary Testing of a Device for Electrostatic classification of Submicron Airborne Particles," J. Appl. Phys. 32, 955-7 (1961).

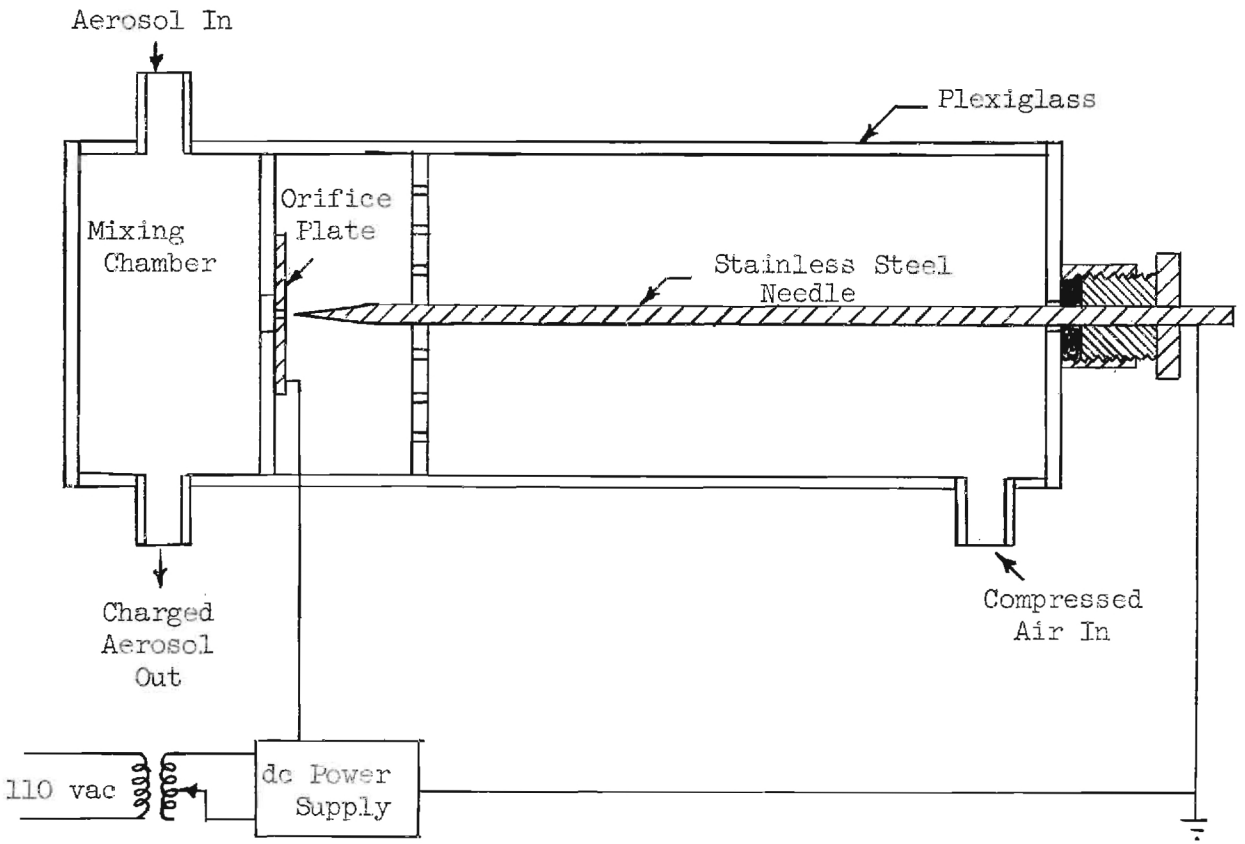

Figure 4. Point-Design Aerosol Charger

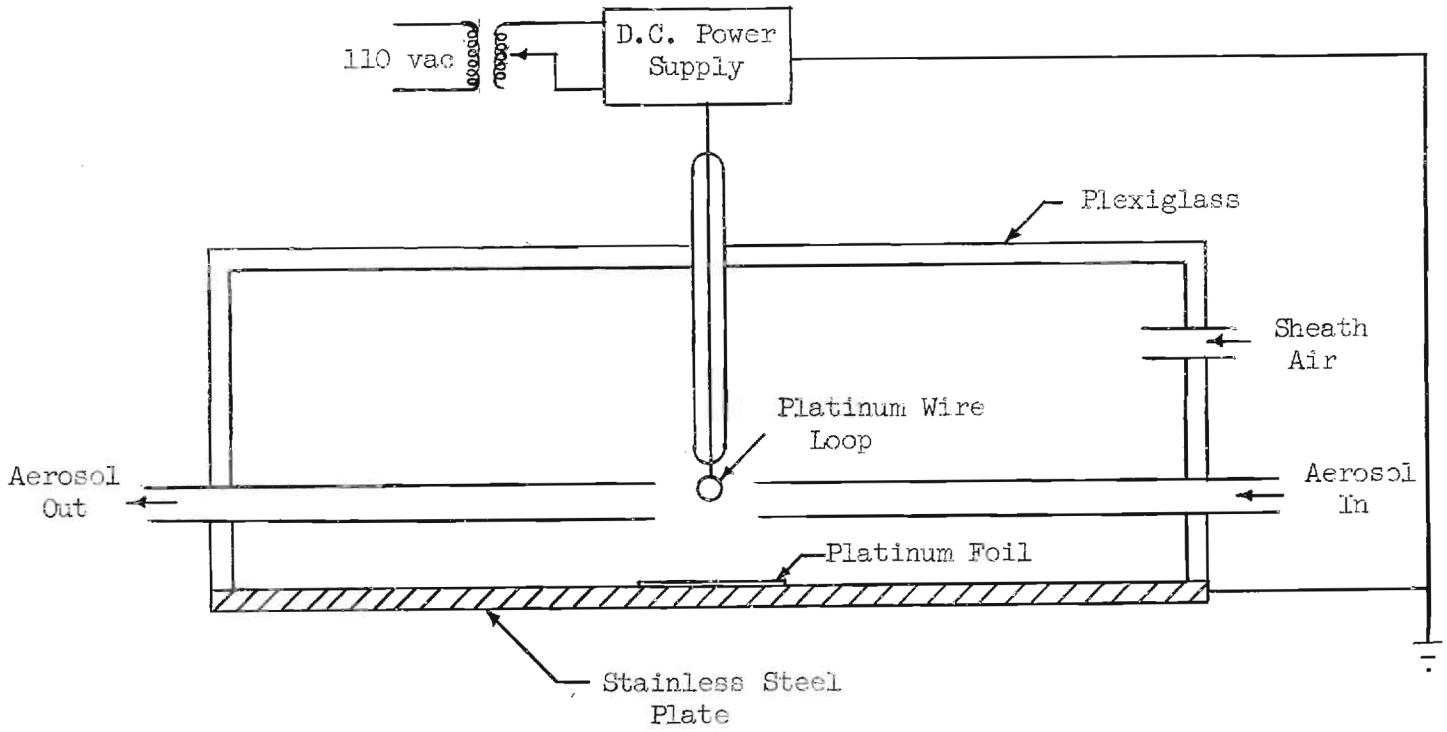

Figure 5. High Velocity Electrostatic Charger

3. Corona Wire Design

A third device for generating unipolar ions to charge aerosols was constructed as illustrated in Figure 6. A very fine wire was suspended horizonally one inch above a horizontal slot approximately 1/4 inch wide and 5 inches long in a stainless steel plate.

A rectangular bar having the same dimensions as the slot was placed approximately 1/4 inch below the slot. The wire was maintained at a potential of approximately 30,000 v abcve ground; the plate containing the slot was maintained at approximately 3,000 v above ground; and the rectangular bar was maintained at zero potential with reference to ground. The gas stream containing the aerosol was passed between the slot and the bar.

In this device, unipolar positive or negative ions produced by the corona discharge around the wires are accelerated toward the plate. A fraction of these pass through the slot and travel on toward the plate at ground potential. Some of these ions collide with the particulates in the aerosol stream which is flowing perpendicular to the ion flow charging the particles by so-called "field charging".

B. Ion Chambers

1. Flat Parallel-Plate Ion Chamber

An ion chamber was constructed of two flat stainless steel plates 100 cm long and 8 cm wide separated a distance of 3 mm from each other with Teflon. The plates were enclosed in a stainless steel electrostatic shield and the bottom plate insulated from the shield by a 3/8 inch thick glass plate. The top plate was insulated from the shield by the glass plate and a Teflon spacer assembly. Figures 7 and 8 show the chamber disassembled. The Teflon

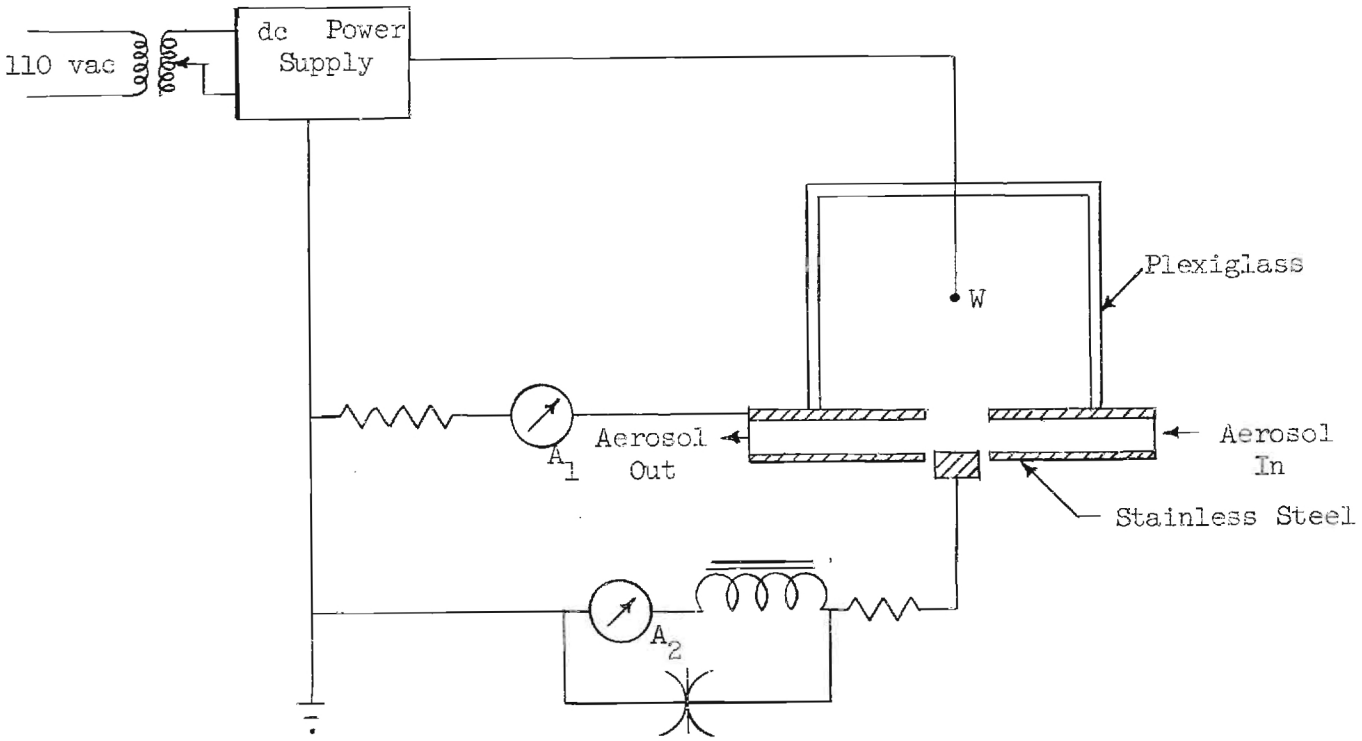

Figure 6. Corona Charging Unit

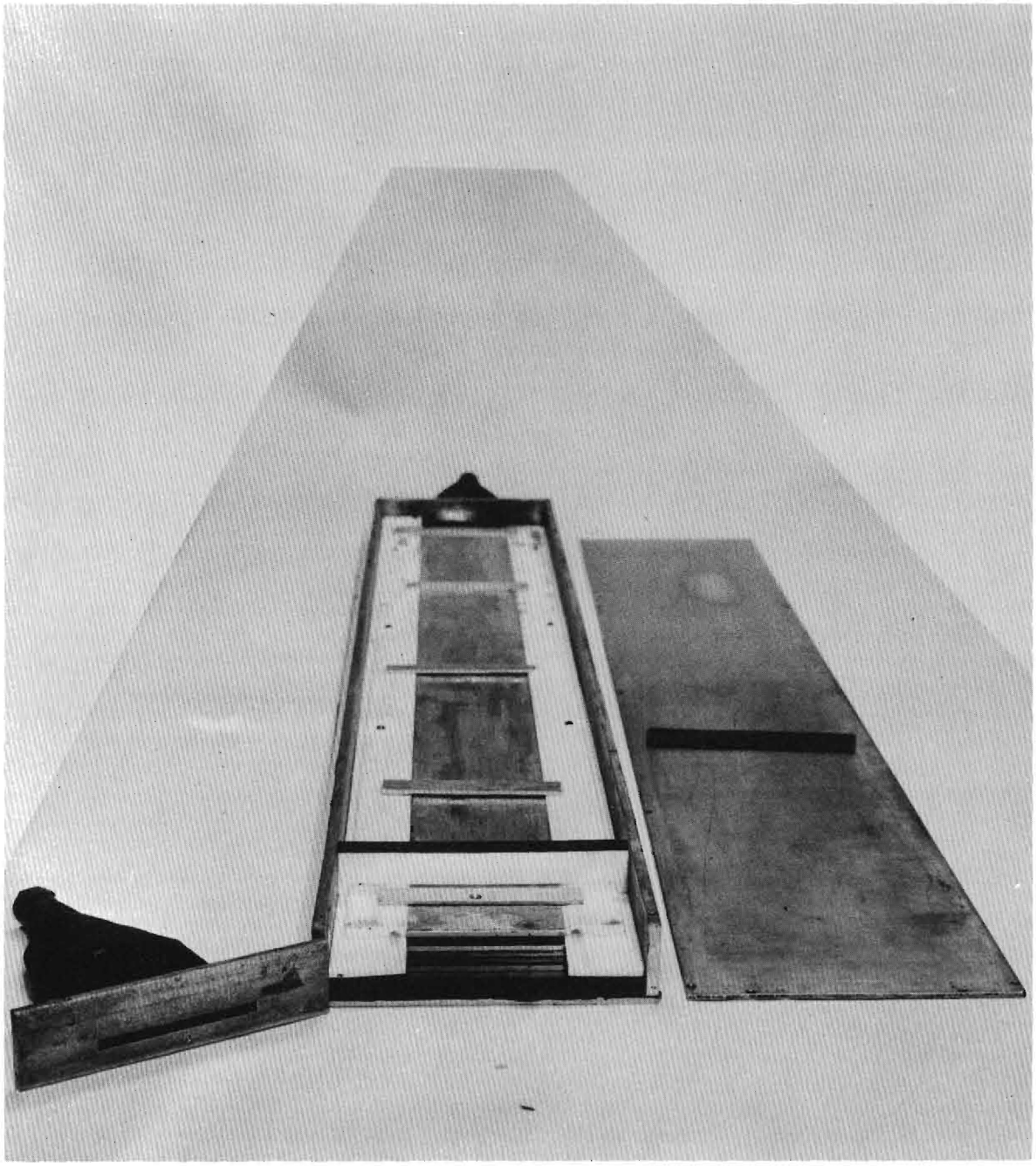

Figure 7. Flat-Plate Ion Chamber, Disassembled, End View.

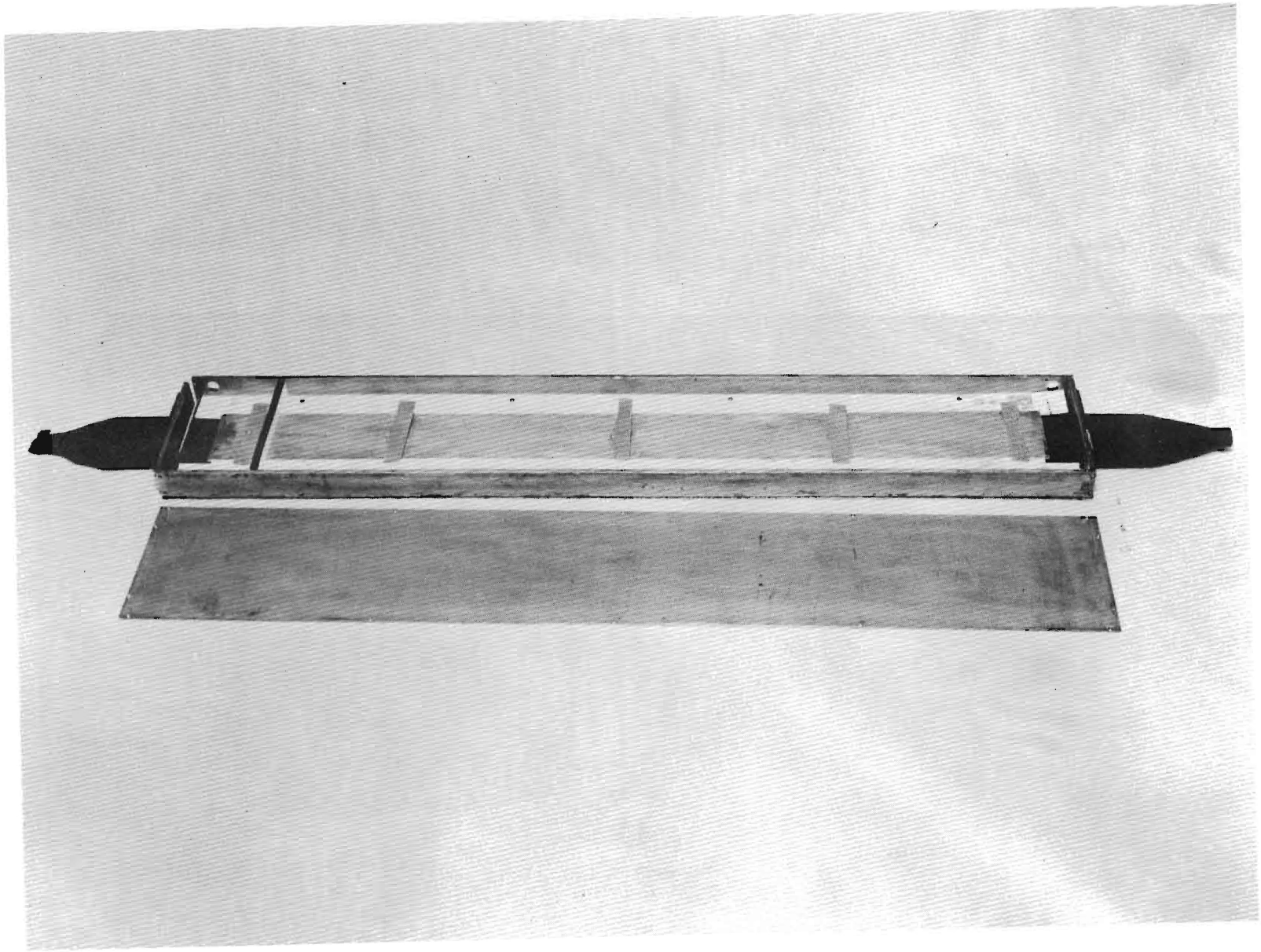

Figure 8. Flat-Plate Ion Chamber, Disassembled, Side View.

spacer assembly extended the length of the plates and restricted the gas flow to the space between them. The chamber was mounted horizontally on small heating elements and the entire unit was maintained approximately 10°C above room temperature to prevent condensation on the insulators within the chamber. The bottom plate was connected to a variable, highly stable, dc voltage supply with a low-capacitance cable of minimum length. The top plate was connected to a microammeter, again with a minimum length of low-capacitance cable to minimize capacitance effects. Entrance and exit channels were provided so that the gas stream containing the aerosol would attain laminar flow before reaching the electrodes.

2. Cylindrical Ion Chamber

This design consisted of two large stainless steel cylinders, the smaller centered inside the larger with a separation between their walls of approximately 1 inch. The smaller cylinder was 18 inches in diameter and 42 inches in length, and the larger cylinder was 20 inches in diameter and 48 inches long. A view of the chamber with its associated electrical equipment is shown in Figure 9. The inner chamber was insulated from the outer with Teflon. The intermost cylinder formed the collector electrode and was connected to a micro-microammeter. The outside cylinder was connected to a low-current, stabilized, variable, high-voltage supply.

3. Multiple-Plate Ion Chamber

The multiple plate chamber consisted of 59 rectangular, stainless steel plates stacked on top of one another and separated from each other by a distance of 0.980 inches. Figure 10 is a picture of the chamber partially assembled. Every second plate was electrically connected in series to a variable

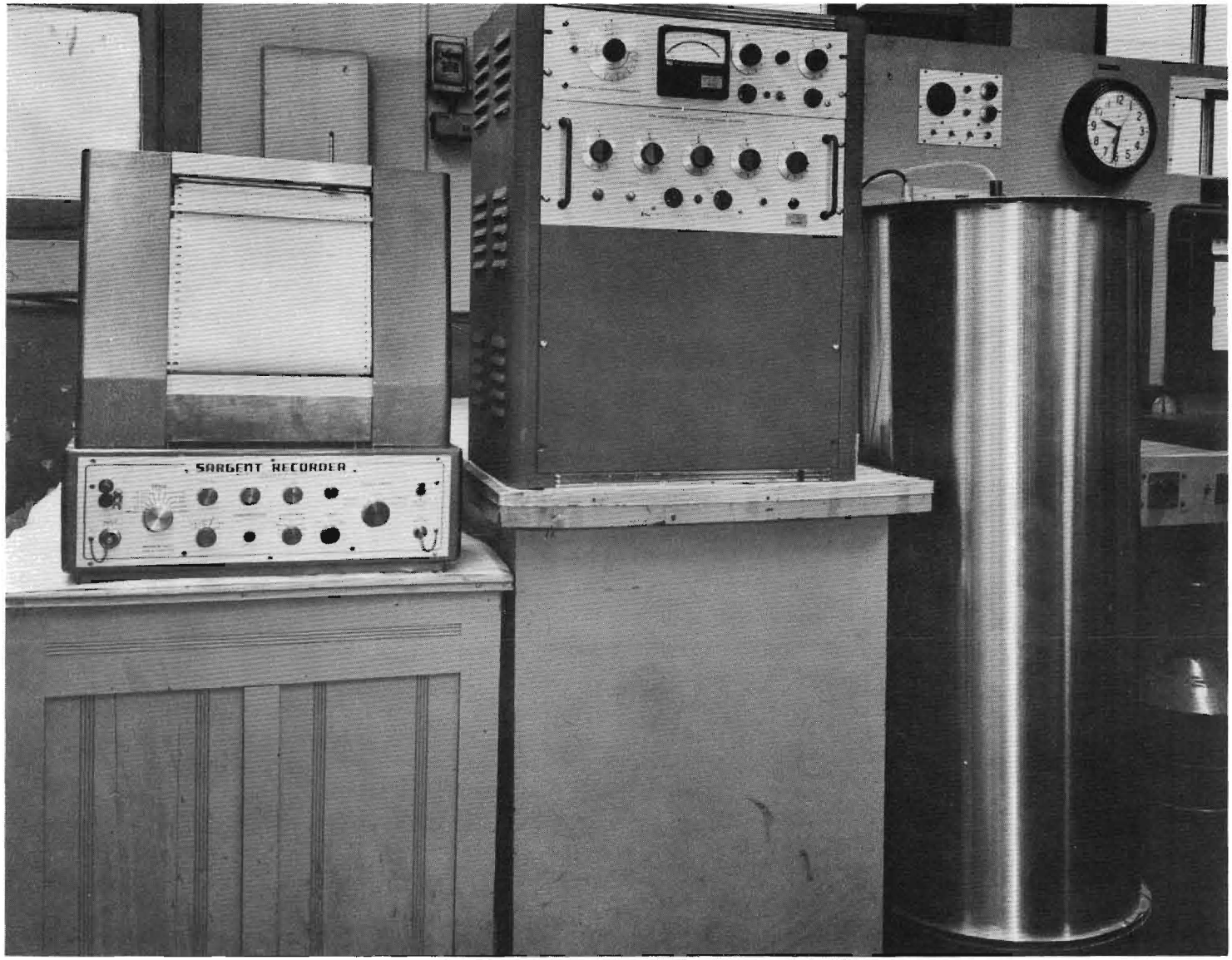

Figure 9. Cylindrical Ion Chamber and Associated Equipment.

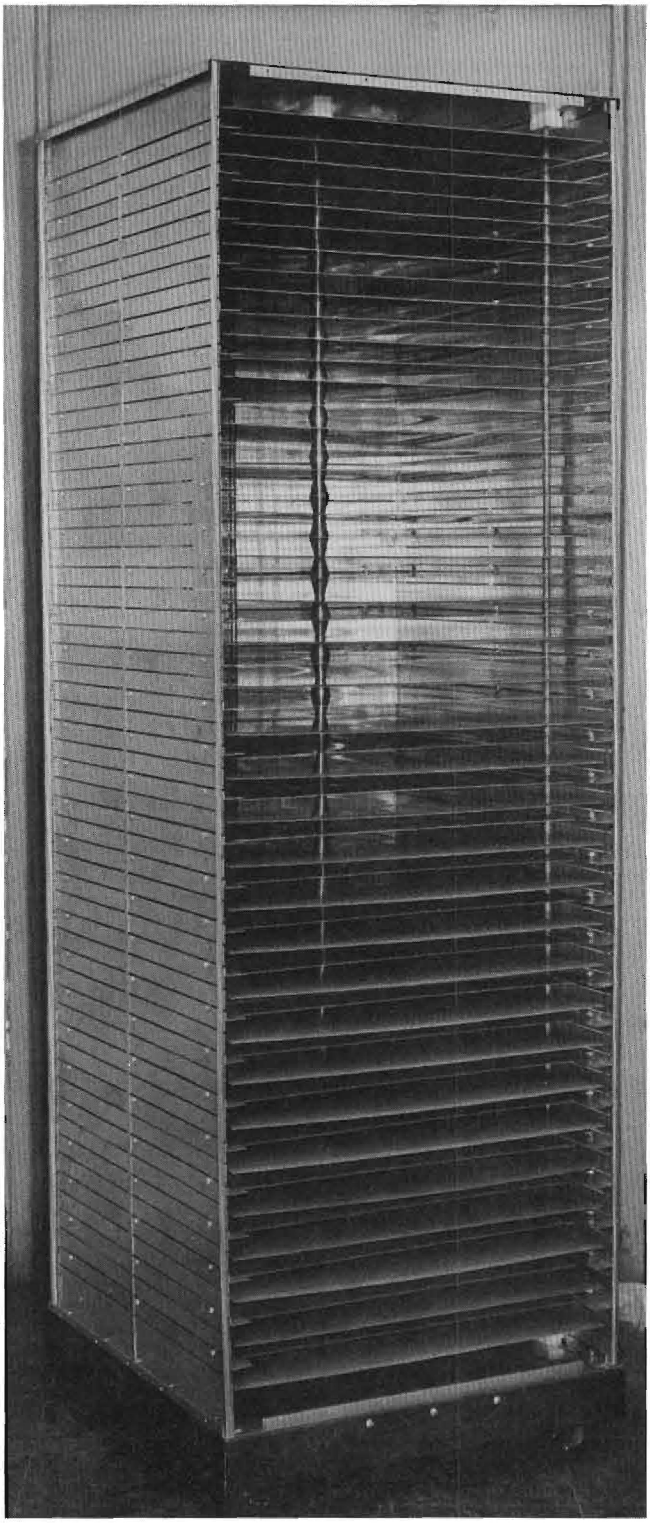

Figure 10. Multiple-Plate Ion Chamber, Partially Assembled.

high voltage supply. These intermediate collector plates were 1-1/4 inches smaller than the high voltage plates and were electrically connected to each other by the spacer assembly and to a micro-microammeter. These plates were surrounded by guard rings which extend to the walls of the chamber. The separation between the guard ring and collector plate was 1/8 inch. The collector plates were supported by a spacer assembly in the center of each plate and the ends of the assembly were supported by two Teflon holders for electrical insulation from the chamber walls and the high voltage plates. The high voltage plates had a 1-inch diameter hole in their center to allow passage of and separation from the spacer assembly. The high voltage plates were supported by three spacer rods located near their outside. The rods were mounted in Teflon holders, insulating the high voltage plates from the walls and providing further insulation for the collector plates. Three-fourths inch diameter holes were cut in the guard ring on three sides of the chamber to allow separation from the high voltage plates. The inside wall of these chambers were provided with 1/16 inch horizontal slots opening between each plate for the width of the chamber. A port was provided in the top of the entrance chamber and the bottom of the outlet chamber so that aerosol would be distributed uniformly throughout the system. The chamber with its associated electrical equipment was placed in an attached metal cabinet and the cabinet was grounded to provide further shielding to the system; this final arrangement is shown in Figure 11.

C. Associated Equipment

1. Electronic

The electronic equipment associated with the various chambers consisted basically of a micro-microammeter, Model 415, and a regulated, variable

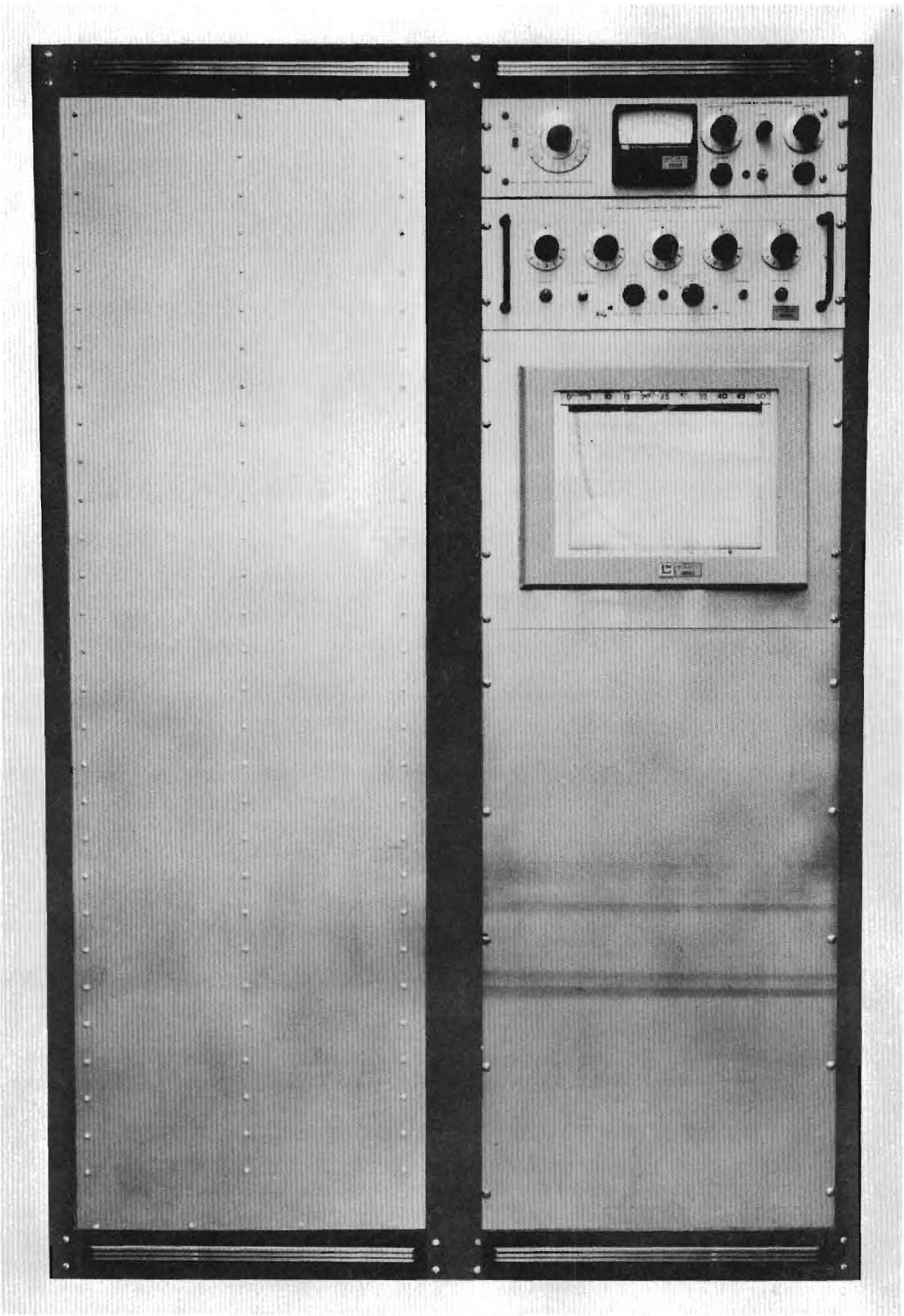

Figure 11. Multiple-Plate Ion Chamber, Assembled.

high voltage supply, Model 241, both manufactured by Keithley Instrument Inc., Cleveland, Ohio. A Leeds and Northrup, Type W, recorder and a constant voltage transformer completed the major pieces of equipment.

The current measuring range of the micro-microammeter was 10×10^{-4} to 3×10^{-13} amps. The high voltage supply put out from 0 to 1000 v in 1 volt increments. The connections between the high voltage supply and the chamber and between the micro-microammeter and the chamber were by shielded low-capacitance cable in order to speed the response of the system. The Leeds and Northrup recorder was modified with a voltage divider so that full scale on the micro-microammeter corresponded to full scale on the recorder. Constant voltage transformers were used both to stabilize the voltage and to isolate line interference.

2. Aerosol Generators

Several types of aerosol generating devices were used. For atomizing liquid solutions with dissolved components, a DeVilbiss, No. 180, atomizer, and an air-blast atomizer were employed. A four-cycle, 2 hp. gasoline engine, a bunsen burner, a blow torch, etc. were used as other generating devices.

Natural aerosols as found in the air of the laboratory and outside it was also utilized. One of the aerosol generating trains is shown in Figure 12.

3. Aerosol Conditioners

Aerosols produced by atomization were used as reference substances. They were passed through a flask partially filled with lithium chloride and contained in a cold bath and then through a heated bath to produce low humidity conditions and to insure that solid particles existed. Particle size distributions as determined by ion counters could then be reliably compared with those made from electron micrographs.

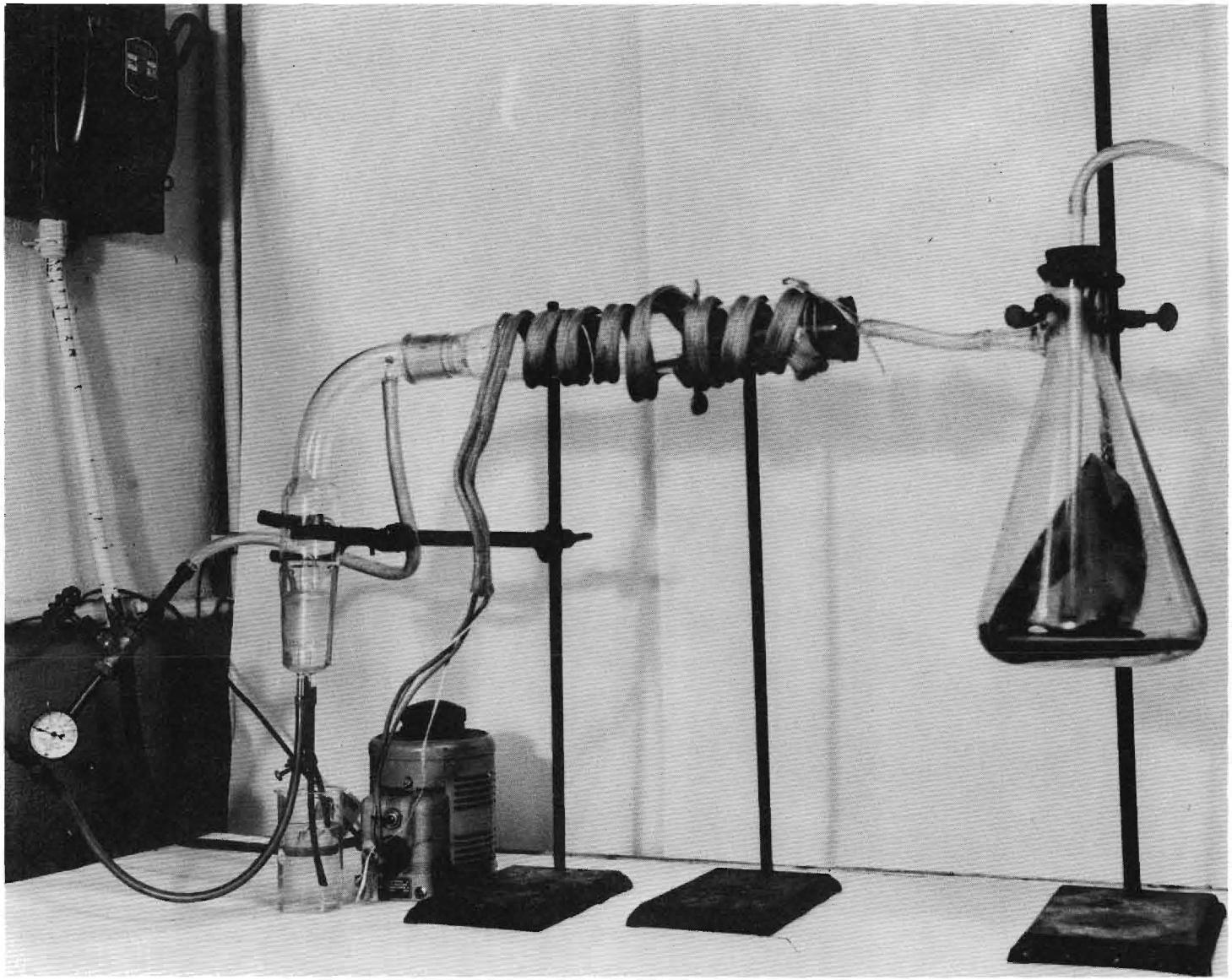

Figure 12. Aerosol Generating System.

4. Sampling

A thermal precipitator was used to obtain samples for electron micrographs. An electron microscope grid was placed on the cold surface of a high-capacity thermal precipitator and the particles were collected directly on the grid.

D. Test Procedures

1. Flow Systems

The ion chamber was connected to the associated electrical equipment as shown in the schematic diagram of Figure 13. The associated electrical equipment was allowed to warm until it became stable. Of course, when the system was being used continuously the electrical equipment remained on.

If the aerosol was generated with the DeVilbiss atomizer, the latter was connected to a regulated air line set at approximately 13 pounds gauge pressure. When other types of generators were used the aerosol was first collected in large plastic bags and then forced through the system by collapsing the bag at a uniform rate. This eliminated pulsing such as produced by a gasoline engine, for example.

After the aerosol was generated it was passed through the conditioning chambers where the particles were dried and the relative humidity of the gas stream was lowered to approximately 40 per cent. The aerosol then passed through a flow meter and into the ion chamber. The flow rate was adjusted by using only a portion of the stream.

After constant flow was established, the voltage to the chamber was changed in increments, and the current, voltage, and flow rate were recorded. When artificial charging was desired, one of the charging devices as described above

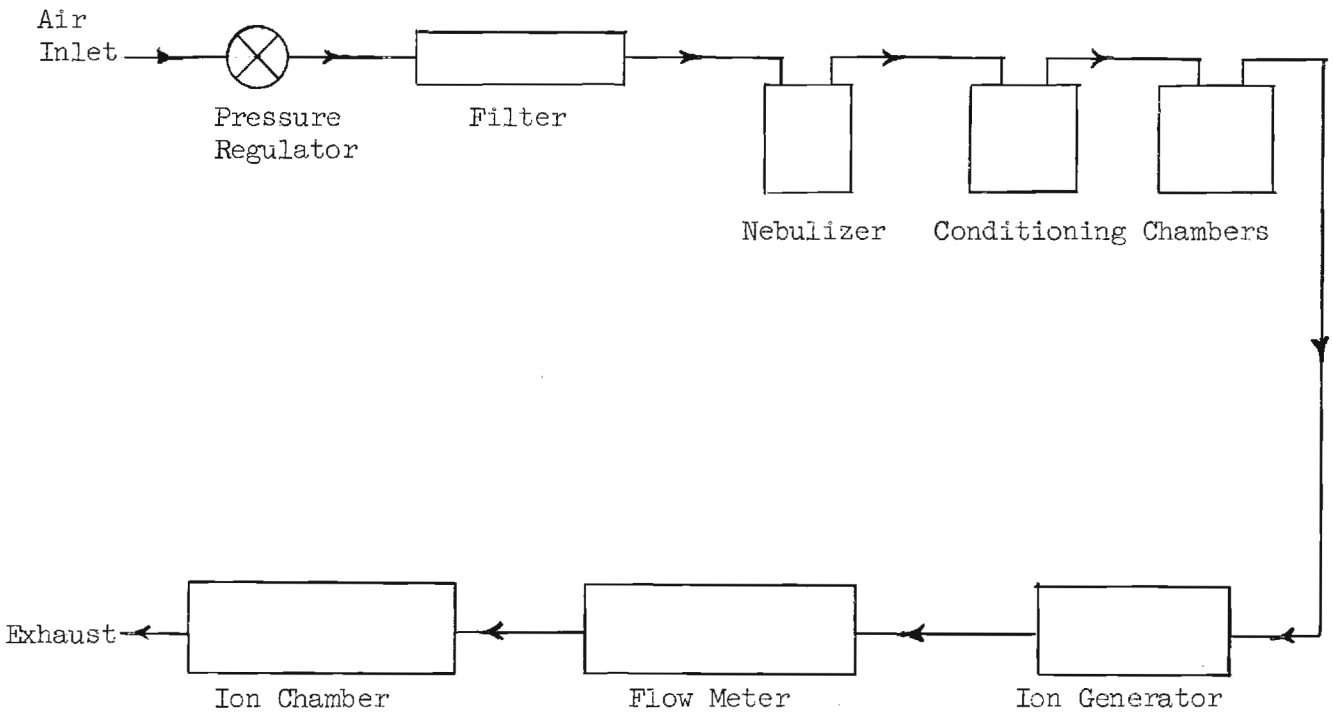

Figure 13. Schematic Arrangement of Ion-Chamber Components

was placed in the system between the conditioning chambers and the flow meter.

2. Static Systems

In the static system of operation, the ion chambers were filled by passing aerosol into them in essentially the same manner as described for the flow systems. However, no voltage was applied to the plates during the filling process. After the system was filled with the desired aerosol the recorder was started and a predetermined voltage was applied to the plates of the chamber. Then the chamber was refilled and the process repeated at a new value of the applied voltage. In general, several values of applied voltage had to be used to cover the mobility range of interest. A typical decay curve is reproduced as Figure 14.

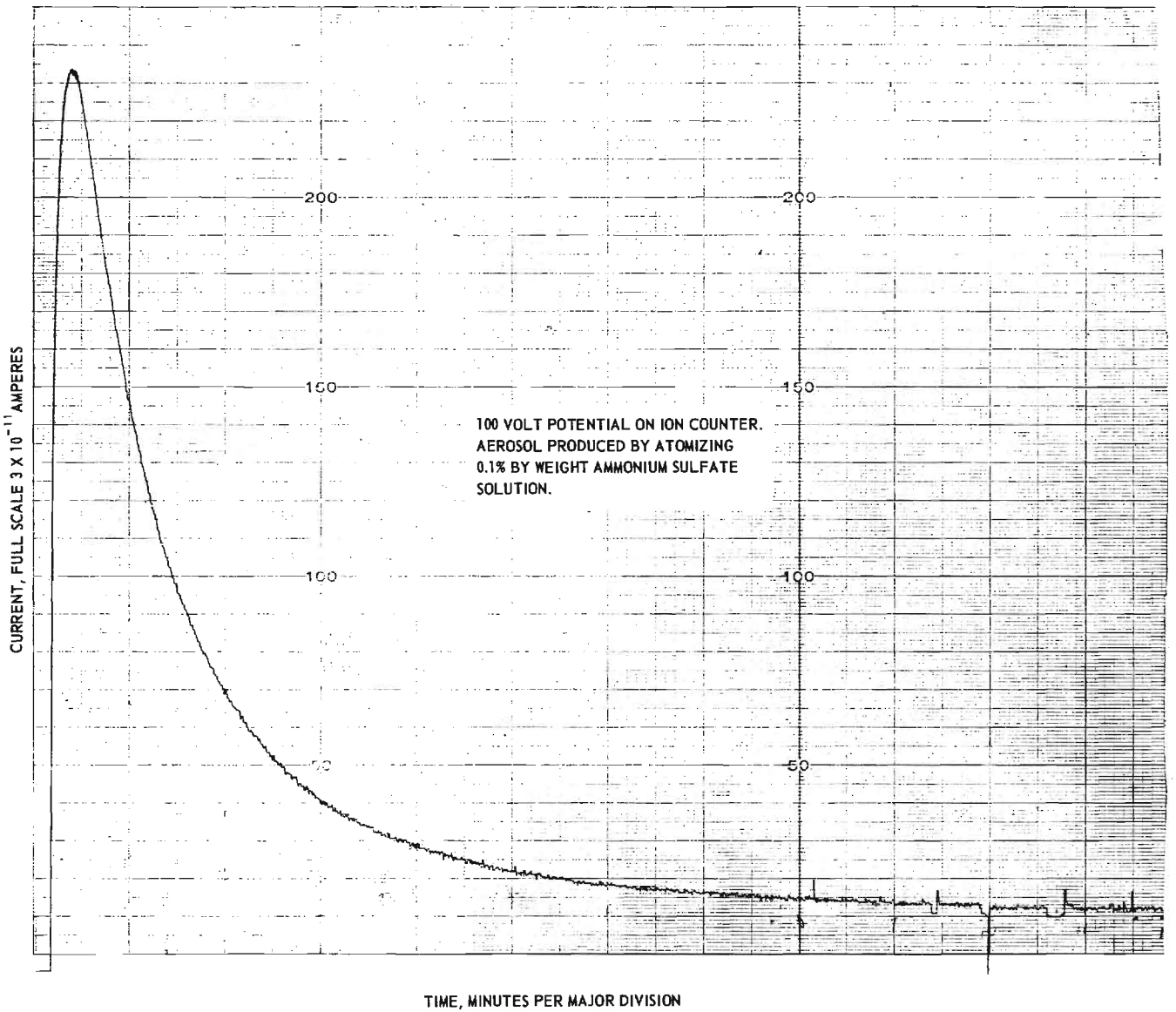

Figure 14. Typical Decay Curve.

V. EXPERIMENTAL RESULTS

A. Artificial Charged Aerosols

The point-to-orifice ion generator was first used on particles produced with an atomizer and was found to be unstable over the period of time required to make a particle size distribution. The separation between the point and the orifice, the sharpness of the point, the applied voltage, and the pressure drop across the orifice were all critical factors in maintaining effective charging. Keeping the point sharp was most difficult, and it was virtually impossible to reproduce the same charging conditions consistantly.

The wire loop design was tested first for stability. Laminar flow of aerosol through it was maintained between the platinum wire loop and the platinum foil plate. A filtered sheath of air surrounded the main aerosol stream. This diluted the aerosol which was undesirable and in addition some of the particles were forced from the laminar stream due to the electric field between the loop and the platinum foil. The operation of this device was unstable and results were not reproducible. Hence, no size distributions were made with it.

The corona wire device showed good stability and reproducibility. Electrostatic precipitation was a major fault with this design, however. Figure 15 shows the effect on particles with different mobilities. At low ion chamber voltages, particles of the higher mobilities were primarily collected while at the higher voltage both low mobility particles and high mobility particles were captured. The curve labeled 400 volts, for example, represents the behavior of the entire mobility range because all mobility are collected. The current at A_1 and A_2, Figure 6, was monitored and it was found that at 6kv corona conditions began. This is just where the current starts to decrease

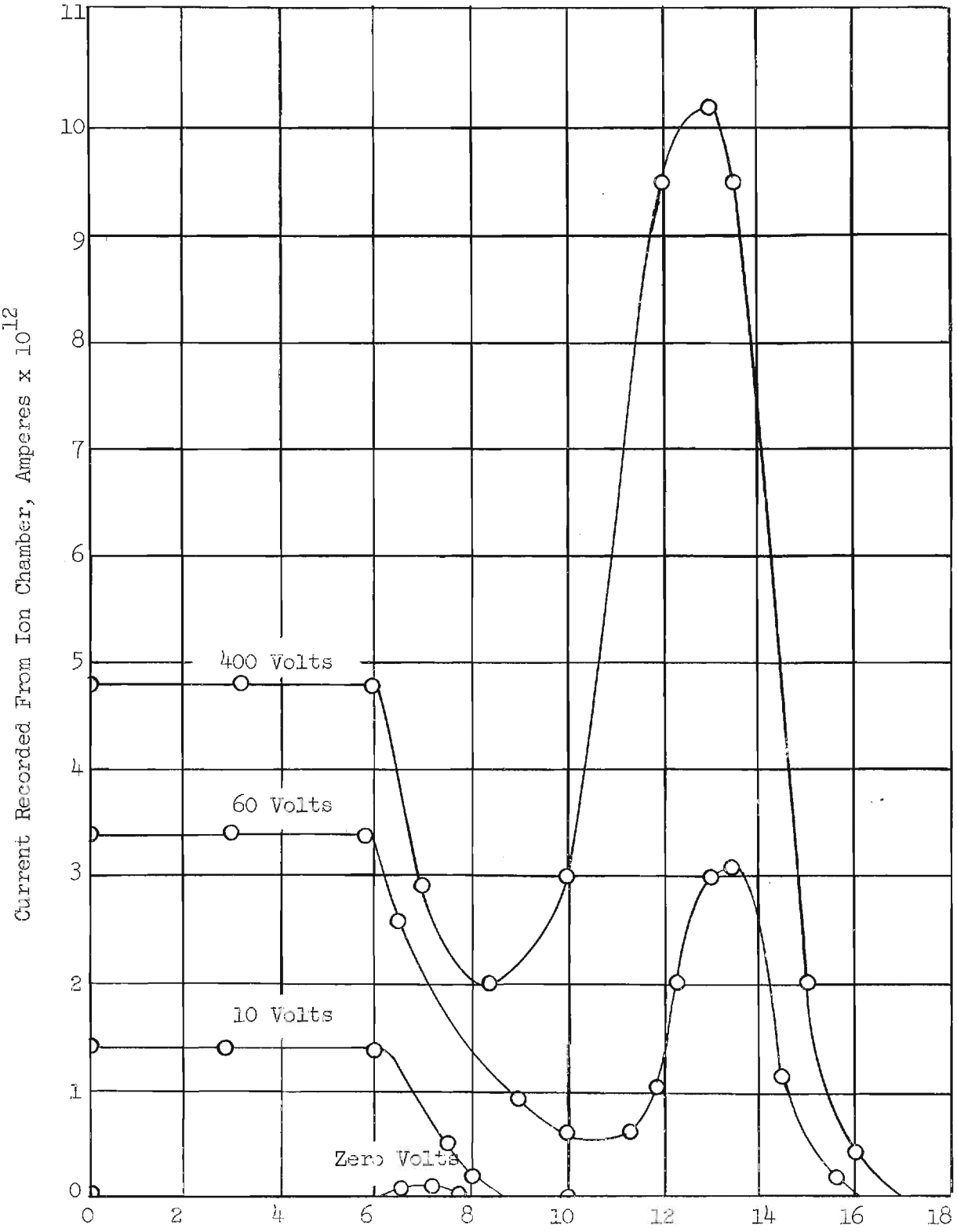

Figure 15. Corona Charger Performance Characteristics

as shown by the ion counter, indicating electrostatic precipitation of the particulates. The sharp increase in ion current at 12,000 v on the charger was reproducible and charging tests and sampling were carried out at this voltage. Considerable effort was expended in an attempt to obtain suitable charging and to obtain an analysis of the resultant ion chamber data. These attempts failed to produce consistent results. It became apparent also that even had an analysis of the aerosol entering the ion chamber been accomplished, the results would have been relatively meaningless in view of the large fraction of the smaller ions which were precipitated in the charger. The aerosol entering the ion chamber was no longer representative of the original aerosol. In view of this and the lack of reproducibility of the data it was decided to abandon charging techniques and to attempt to analyse the particulates in the air under normal air conditions.

B. Naturally Charged Aerosols

The ultimate goal of this project was to design an ion chamber and to develop the analytical techniques from which a size distribution and other quantitative measures could be made of normal air particulates. After attempts were abandoned to charge artificially the particulates, the initial flat plate plate ion counter was tried as a flow system using normal laboratory air which was presumed to be fairly high in particulate content. This system did not give a readable ion current with the air as normally existing although it was observed that a gas flame or a cigarette placed near the inlet produced measureable currents. As a check on the operation of the system, an artificial aerosol with characteristics known from previous investigations was prepared by a nebulizing 0.1 per cent ammonium sulfate solution after which the aerosol was

heated and dried in suitable chambers described elsewhere in this report[7][8]. The aerosol was then introduced into the ion chamber. Consistent, reproducible results which compared favorably with distributions of the same aerosol thermally deposited on electron microscope grids were obtained. Such a comparison is given in Figure 16.

Having concluded that the initial flat plate chamber was too small to give sufficient current for analysis, it was decided to build a larger system. Coaxial cylindrical geometry was chosen for this chamber for mechanical and electrical shielding convenience. Its volume was 150 times as large as the original flat plate chamber. The operation of this chamber was checked using the nebulized artificial aerosol of ammonium sulphate in a manner similar to that described above. Once again consistent, reproducible results which checked well with thermally precipitated electron microscope analyzed samples were obtained, a comparison being shown in Figure 17. In the course of this checking it was found that lower electrical noise levels could be obtained by using a non-flow ion current decay mode of operation than by using a flow system. Accordingly, analysis of the decay curves was undertaken. This analysis proved to be no more difficult than the analysis of the flow system data, and, moreover, offered in addition to the lower electrical noise the advantage of not requiring flow stability to be maintained for extended periods of time. The details of the analysis are given elsewhere in this report.

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(7) Orr, C., Jr., Hurd, F. K., Hendrix, W. P., and Junge, C., "The Behavior of Condensation Nuclei Under Changing Humidities," J. Meteorology 15, 240-2 (1958)

(8) Orr, C., Jr., Hurd, F. K., and Corbett, W. J., "Aerosol Size and Relative Humidity," J. Colloid Sci. 13, 472-82 (1958).

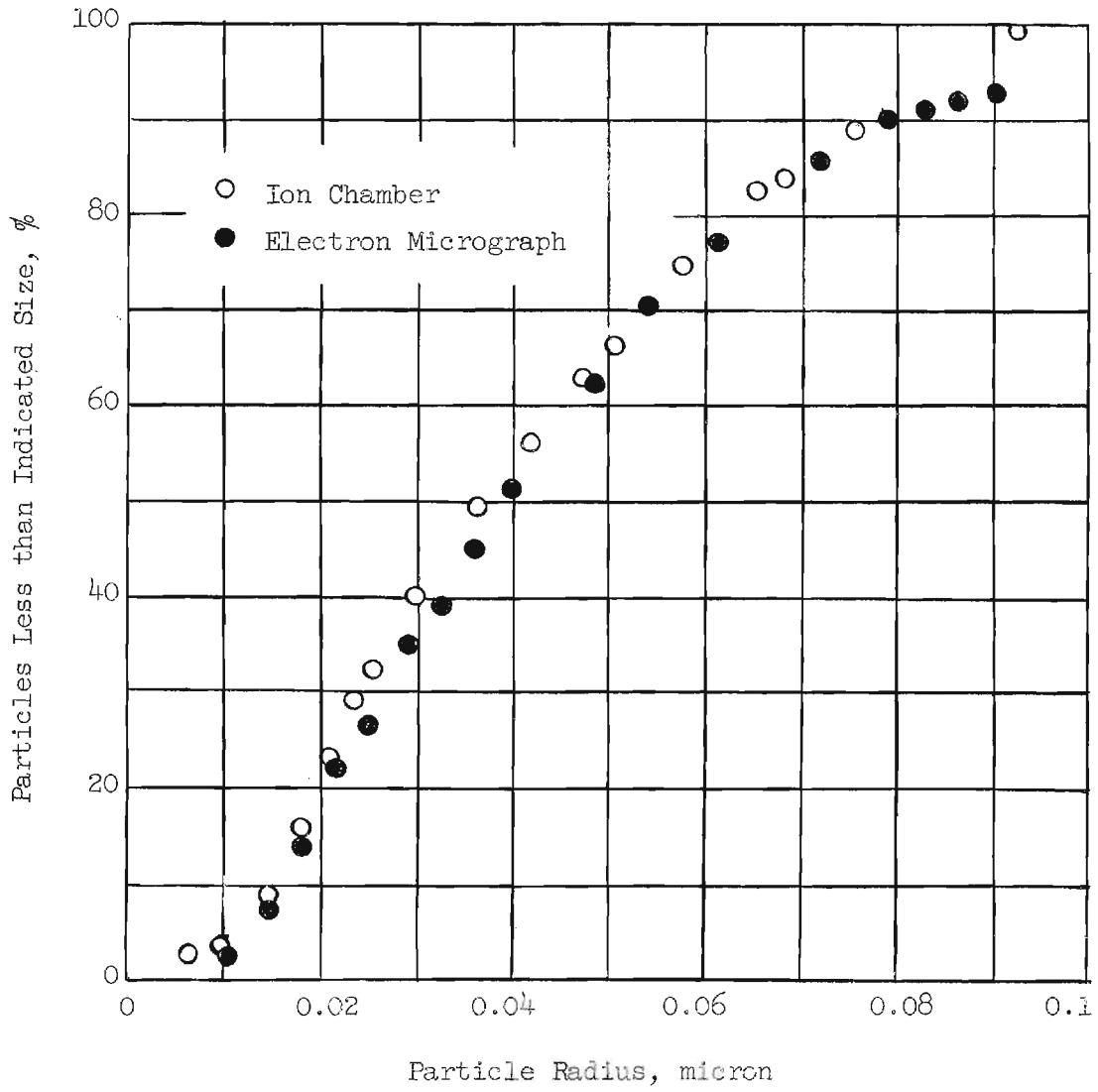

Figure 16. Comparison of Flat Plate Ion Chamber Results with Analysis Made from Electron Micrographs Using An Aerosol of Ammonium Sulfate.

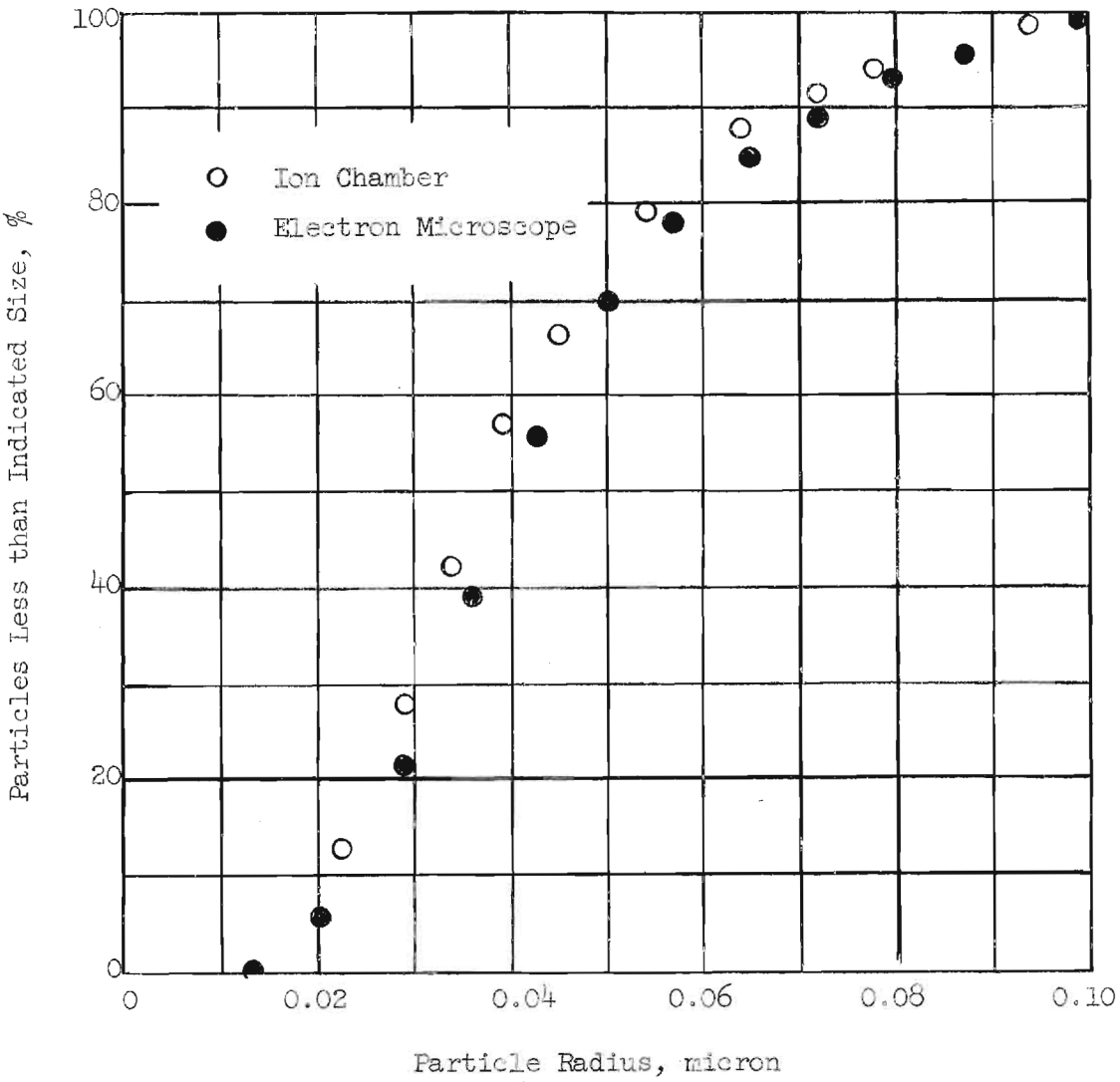

Figure 17. Comparison of Coaxial Ion Chamber Results With Analysis Made from Electron Micrographs Using an Aerosol of Ammonium Sulfate.

Unfortunately, this system also proved to be too small to give a usable ion current when filled with the normal laboratory air, although it appeared to be on the verge of sufficient sensitivity on days when certain other activities in the laboratory contributed contamination.

In view of the apparent marginality of the cylindrical chamber it was decided to make a static system of still greater volume. Accordingly, a multiple flat plate design as shown in Figures 10 and 11 was constructed. It's active volume was approximately 0.4 m^3. This chamber when checked with the nebulized ammonium sulphate aerosol as previously described proved also to behave quite satisfactorily. A typical result is shown in Figure 18. When filled with the normal laboratory air it did not give a usable ion current, however. This result was disappointing and suprising in that it means that the number of naturally charged particles in the size range for which this ion chamber is sensitive is far lower than has been presumed. This result, as developed in the following section indicate that there are less than 2.5×10^3 /cm^3 charged particles (positive or negative) in the size range from 0.02 to 0.1 micron in normal room atmospheres.

C. Sensitivity of Multiple-Plate Ion Chamber

The minimum usable current sensitivity of the micro-microammeter is limited by system noise. It was found by experience that half scale on the 10^{-12} ampere range was the minimum usable current and that a five minute decay curve was about the minimum usable decay time. Using these figures and a normal decay curve (which means approximately a normal particulate distribution) it can be calculated that this system requires approximately 1.5×10^{-10} coulomb of charge on the ions for them to be analyzed. The chamber volume was approximately 4×10^5 cm^3; this means a charge of 4.0×10^{-17} coulomb/cm^3.

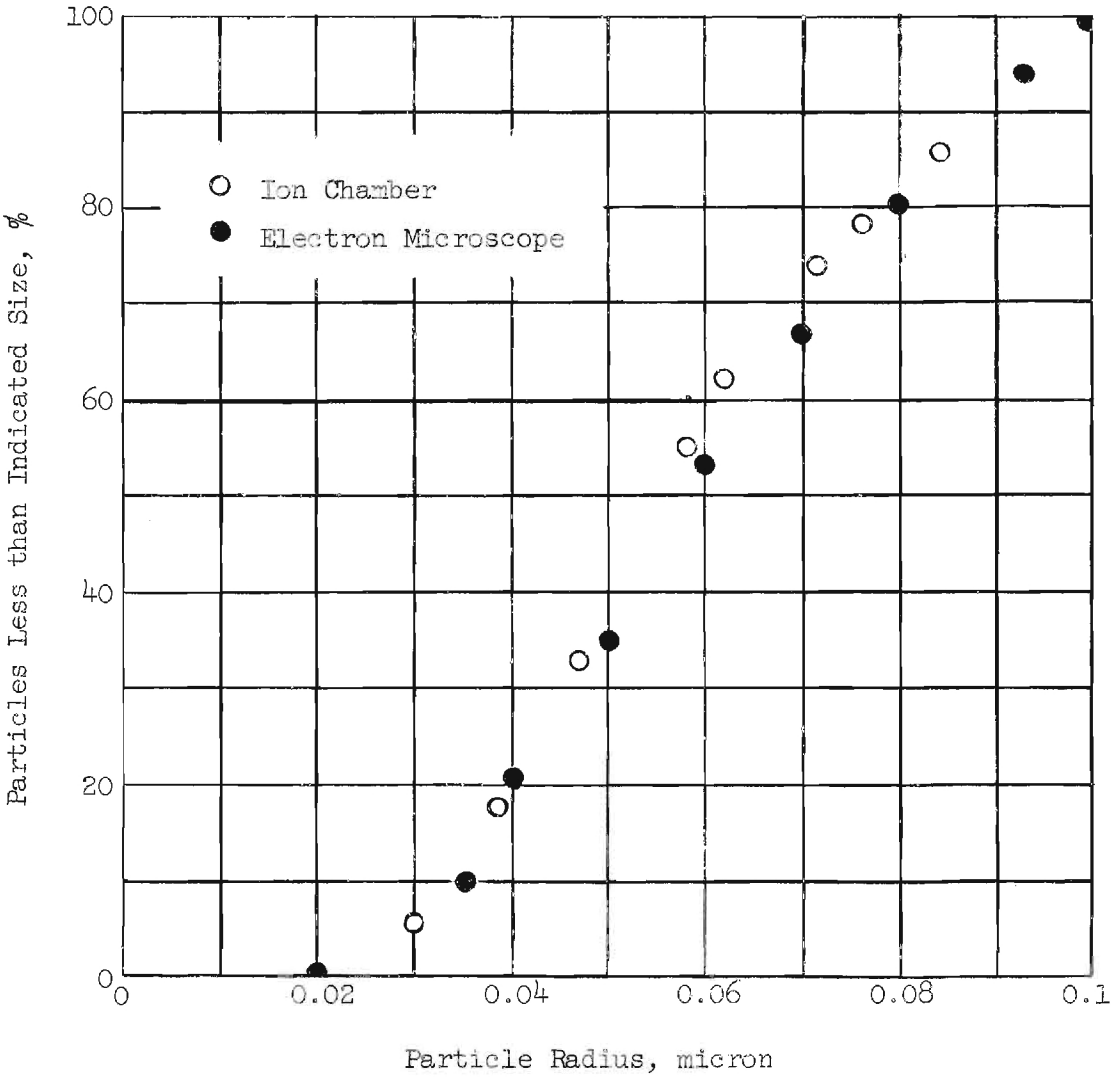

Figure 18. Comparison of Multiple Plate Ion Chamber Results with Analysis Made from Electron Micrographs Using an Aerosol of Ammonium Sulfate.

With one electronic charge per particle this corresponds to 2.5×10^3 charged particles/cm^3. With 25 volts on the system, the range of its sensitivity for particulates is from approximately 0.01 to 0.05 micron radius and with 100 volts the range of sensitivity is from approximately 0.02 to 0.10 micron radius. In as much as the system failed to give a usable current for normal laboratory air (which was not particularly clean) it is concluded that air with normal contamination contains less than 2.5×10^3 charged particles/cm^3 in the size range from 0.02 to 0.10 micron radius. This is far lower than was presumed at the beginning of the project.

D. Tobacco Smoke

Assuming the particulates to be singly charged, the size distribution of fresh tobacco smoke was determined to be as given on Figure 19.

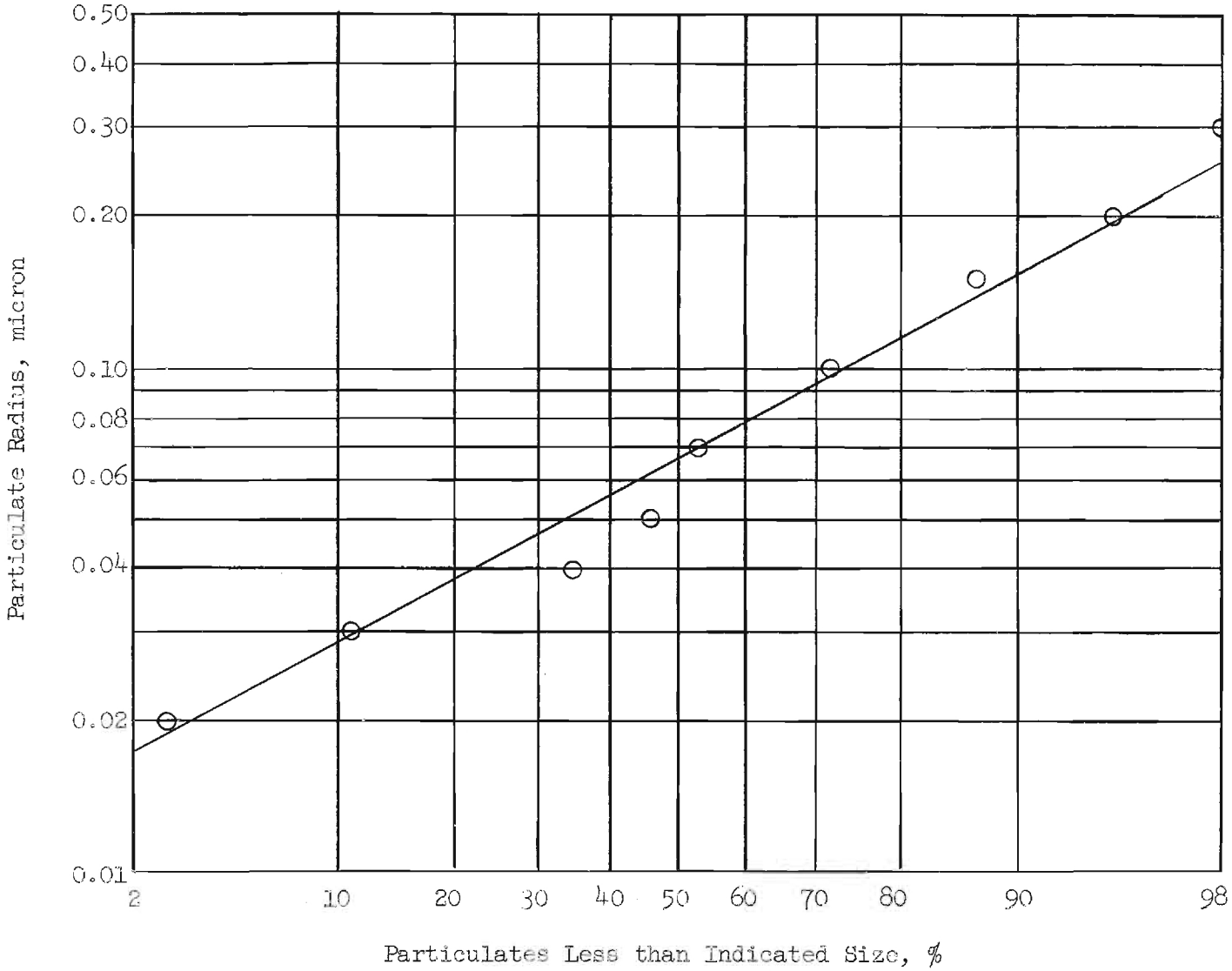

Figure 19. Size Distribution of Tobacco Smoke

VI. CONCLUSIONS

This investigation has been seriously hampered by the fact that no way was found to charge particulates in proportion to their size without precipitating all or most of them. This meant that any analysis was limited to particulates under about 0.1 micron in diameter, since these alone can be assumed to carry only one electronic charge and to have their behavior in an electric field rigorously related to their size.

Aside from the difficulties described above, it has been shown that:

1. Numerous designs of ion-chambers are feasible.

2. The decay-curve type of operation is readily analyzed and results from it are satisfactory; this may prove to be a valuable mode of operation under certain situations.

3. Ion-counters are completely feasible for analyzing synthetic aerosols of small size, e.g., tobacco smoke.

VII. RECOMMENDATIONS

Once particulates are able to be charged in proportion to their mass or volume and maintained in an aerosol, ion-counter techniques will become invaluable in aerosol research and air pollution analysis. Efforts in this area should be concentrated on understanding particulate charging behavior.

Respectfully submitted,

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Approved:

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Chemical Sciences and Materials Division